Exploration of the Southern California Borderland

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E/V *Nautilus* cruise NA075 returned to the Southern California Continental Borderland, an area that remains largely unexplored. Part of the broader North America-Pacific plate boundary, this region extends ~300 km west of the San Andreas Fault and displays an unusually rugged physiography. During the cruise, the multibeam sonar mapped ~5,200 km^2 of seafloor, and ROVs *Hercules* and *Argus* were deployed for 16 dives to explore geological and biological targets (Figure 1) and collect samples.

Submerged Marine Terraces

Submerged marine terraces provide information about ancient sea levels, vertical tectonic motion, plate boundary evolution, and seismic hazards. In 2015, *Nautilus* explored submerged marine terraces exposed in a submarine canyon near Santa Catalina Island. Fossils recovered from rock samples provide age constraints for the deepest submerged terraces surrounding the island (Castillo et al., 2015). We continued the transect in 2016 to determine the ages of Santa Catalina's uppermost terraces. We targeted seismic horizons that corresponded to a time when the terraces were exposed on land during the Wisconsinan (~20,000 years ago) and Illinoian (~145,000 years ago) glaciations when sea levels were ~100 m lower. Radiometric dating of these samples will constrain the position of Santa Catalina's shoreline during the first human occupation of North America. Similar dives were conducted on several shallow submerged banks to investigate vertical tectonic motion and to establish activity on numerous offshore faults in the California Continental Borderland.

Fault Zones

The Santa Cruz-Catalina Ridge and Ferrelo active fault zones were explored on several dives. Dive tracks targeted fault zones exposed in canyon walls, and ROV observations revealed some characteristic expressions of active faults. Pressure ridges—elongate ridges with relief of up to a few hundred meters that mark convergence along a strike-slip fault—were identified from our new multibeam bathymetry and then investigated with *Hercules*. We mapped a pressure ridge within a narrow "hillside valley" on the flank of Santa Cruz-Catalina Ridge and another at the base of Southwest Bank and found both consistent with large-scale transpressional structures. The large extent of these features suggests infrequent large earthquakes (M_w7) and potential for local tsunami generation.

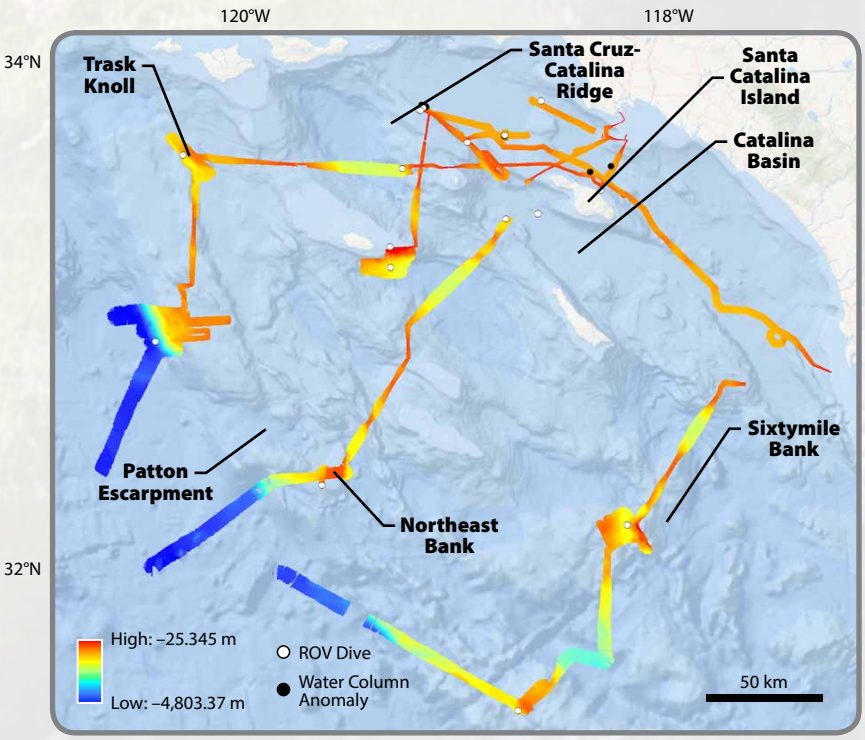

Figure 1. E/V *Nautilus* multibeam mapping coverage, water column anomalies, and ROV dive sites. *Service layer credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors*

Cold Seeps

We visited three seep areas associated with known faults or folds and explored a water column anomaly in Santa Monica Basin that turned out to be a large seep site with two distinct provinces—flat in the north and hummocky in the south. White, gray, orange, and yellow bacterial mats were present as well as one bubble plume (0.35°C) and a low abundance of megafauna, likely due to low oxygen concentrations (~1.8 µM). Seismic data collected by the USGS in 2014 suggested the possibility of cold seeps on Kimki Ridge in Catalina Basin, and we explored two of the three potential sites. The first was covered by a widespread layer of authigenic carbonate and patches of whitish microbial mats, and was littered with dead clams. The second showed substantially more evidence of seepage, including a greater abundance of live clams, microbial mats, and authigenic carbonate.

Seamounts and Guyots

Shallow banks occur throughout the offshore California Continental Borderland. We mapped four of them and then visited them with *Hercules*. Their flat summits, now lying in 120 m to 550 m of water, are interpreted to have been subaerial in the geological past and are now subsiding. Trask Knoll, Southwest Bank, and Sixtymile Bank were uplifted as a result of tectonic activity on a set of northwest-oriented faults, as evident from the bathymetric data, and as interpreted from existing seismic reflection profiles. Northeast Bank, on the other hand, is a volcanic guyot (Paduan et al., 2009). Rock samples collected from presumed ancient shorelines on all four banks are awaiting analysis to constrain their rates of subsidence.

Deep-Sea Biogeography

Megafaunal communities in this region varied greatly by location, depth, and benthic habitat characteristics. Exposed rocks and outcrops served as diversity hotspots, hosting a variety of sponges, tunicates, brittle stars, crinoids, and anemones (Figure 2). Squat lobsters, hermit crabs, serpulid calcareous tubeworms, bryozoans, and nudibranchs were also present in smaller numbers. Asteroids, holothurians, ophiuroids, echinoids, shrimps, hexactinellid sponges, and several species of crabs were associated with both soft and hard seafloor. Multiple kinds of deep-sea octocorals were observed along with some hard coral species, particularly at seamounts and in heavily rocky areas, but were overall not abundant. Other notable fauna include sea pigs, jellyfish, sea pens, acorn worms, scallops, and seep-related benthic communities.

Benthic-dwelling rockfish from the family Sebastidae, common to the Pacific coast, were frequently observed during dives. These fishes—notable for their venomous spines, long lifespans, and fisheries importance—were observed over a wide depth range (100 m to ~1,400 m) and were often found in rocky seafloor areas. The most common species was *Sebastolobus alascanus* (shortspine thornyhead), along with other *Sebastes* spp. rockfish. Other common fishes encountered included grenadiers, soles, morid cods, eelpouts, sablefishes, hagfishes, snailfishes, occasional *Bathysaurus* sp., snipe eels, skates, catsharks, and chimaeras (*Hydrolagus* spp.).

Several species of cephalopods were observed in this region. The giant Pacific octopus (*Enteroctopus dofleini*) was found at almost every dive site (Figure 3), and there were multiple sightings of *Graneledone boreopacfica* and *Grimpoteuthis* sp. (i.e., dumbo) octopods. The googly eyed stubby squid (*Rossia pacifica*) as well as other squid species were encountered.

Whale Falls

During *Nautilus* cruises NA074 (see pages 38–39) and NA075, four previously undiscovered whale falls were found southeast of Santa Rosa Island (90 m depth), on Sixtymile Bank (370 m depth), on Northeast Bank (437 m depth), and on Patton Escarpment (1,094 m depth), all at late stages of decomposition. These are among the shallowest natural whale falls discovered worldwide thus far. The Santa Rosa skeleton is small compared to the other falls and lies in well-oxygenated water, while the others are located within oxygen minimum zones (10–25 µM). The Sixtymile Bank skeleton is that of a mysticete, but its species cannot be determined without a DNA sample from one of the bones. This skeleton was mostly intact, unsedimented, and undegraded, with many bones still in place (Figure 4). The carcass on Northeast Bank was highly degraded and covered with a lot of sediment, and thus may have been on the seafloor for years to decades. Furthermore, several animals were using the bones as hard substrate and for shelter. On the Patton Escarpment whale fall, urchins were grazing on the bones that also showed evidence of microbial mats, suggesting there was still energy in the bones despite their degraded state. There was no visible evidence of *Osedax* or other whale-fall-endemic fauna on any of the carcasses.

Figure 2. Vibrant pom-pom anemones, *Liponema brevicornis*, and a large boot glass sponge occupied by shrimps made up this rocky undersea garden.

Figure 3. A giant Pacific octopus, *Enteroctopus dofleini*, camouflages itself among brittle stars, anemones, serpulid tubeworms, and other encrusting species on a rocky outcrop.

Figure 4. The whale skeleton located among large rocks on Sixtymile Bank was host to several animals, including a coral, a sponge, and sea stars.